Infrastructure Response to Natural and Man-Made Ground Motions: High-Performance Computing and Distributed Sensing for Regional Scale Prediction and Response

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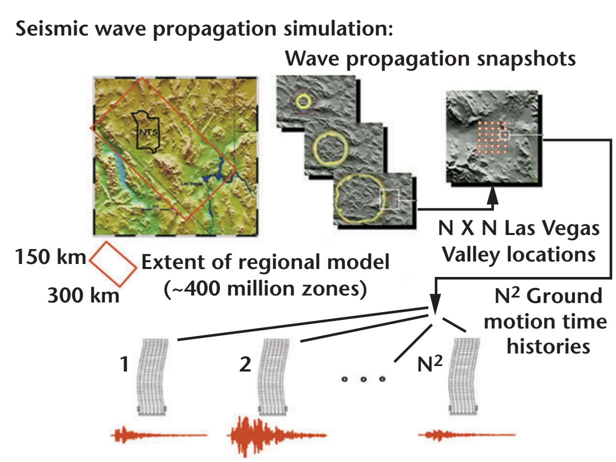
Earthquakes and underground nuclear explosions disperse tremendous energy into geologic strata. This energy propagates large distances in the form of traveling seismic waves, which shake the ground surface and can present a serious hazard to man-made structures. Measurements of earthquake- and nuclear-test-generated ground motions have indicated that the strength of these motions varies greatly with spatial location. Shaking intensity at any site is a complex function of the energy source mechanism, the geologic path along which the seismic waves propagate, and the soil conditions below the site. Also, the direct relationship between the vibrational characteristics of a particular structure and the frequency content of the ground motion will control the degree to which a particular structure is shaken. Until recently, scientists and engineers have relied on relatively simple empirical relationships to estimate the motions to which a structure might be subjected. However, this approach often requires generalization and extrapolation from the existing knowledge base and is limited because of the complexities of wave propagation in the heterogeneous earth. While such approaches might be adequate for basic structure design information (e.g., sizing members, estimating structural deformations), they do not provide detailed information on the response levels that can be expected for a specific earthquake that might occur.

With the advent of massively parallel computers, it has become feasible to simulate the physics of energy propagation from the source through the earth and into a structure. Such an approach makes it possible to generate more realistic site-specific motions that account for the propagation path, local soil response, and interaction between the seismic waves and the structure. In the current study, a regional combined geophysics–structural model is under development. The Southern Nevada region encompassing the Las Vegas Valley and the Nevada Test Site (NTS) (see figure) is serving as a case study for the model development. In addition to providing a regional model of unprecedented scope and extent, the research results will provide a tool to enable the NNSA to assess nuclear test readiness and understand the seismic hazard to the rapidly growing Las Vegas Valley in the event the nation must resume testing. In addition to supporting this national security mission, the research will spin off the tools and knowledge necessary to predict earthquake hazards and enhance safety in earthquake-prone areas.

The regional model framework is called NEVADA and includes a finite-difference wave-propagation code coupled to a special-purpose structural finite-element program that permits linear and nonlinear analysis of building systems. Once a source function at NTS is defined, the regional model propagates seismic energy into the Las Vegas Valley and analyzes the response of a specified structure at preselected locations throughout the valley. This simulation essentially provides a regional seismic hazard assessment with a single program execution.

In FY02, we successfully developed the geophysics model of the Southern Nevada region, created the special structural modeling code, and coupled the codes on Livermore's Advanced Simulation and Computing (ASCI)-level compute engines. We demonstrated the practicality of this coupled regional simulation with actual source-to-structure simulations on the ASCI Blue computer. Our geology characterization was completed in close collaboration with University of Nevada researchers. Parametric simulations with the regional model indicate dramatic variations of ground motion and structural response across the Las Vegas Valley as a result of basin amplification effects. This correlates with the legacy measured nuclear test data, which indicates ground motion amplitude variations by factors as great as 10 to 20 across the Las Vegas Valley.

In FY03 we intend to complete additional parametric studies of regional response to determine the degree to which observed ground motion variabilities are controlled by basin topography or by local soil site response. These parametric studies will also validate the simulation models by comparison with actual ground motion data. The NEVADA framework will be ultimately handed off to program staff to undertake programmatic applications with the software.



A geophysical model of the Southern Nevada region that encompasses the Las Vegas Valley and the Nevada Test Site, combined with a structural model and used to simulate the propagation of seismic energy from the ground to the structure.